Ecological Monitoring Assessment Network Vegetation Monitoring at Royal Roads University

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Abstract

Introduced species were inventoried and the effect on community biological diversity was examined in selected forested sites at Royal Roads University. The sites occur within the endangered Coastal Douglas fir biogeoclimatic zone on southern Vancouver Island. Two long-term 1-ha study plots were established along the forest periphery, in areas of human activity. Four modified 20m^2 plots were also established in the relatively undisturbed interior forest for comparison and a 1-ha plot at Rocky Point was used as a control site. Percent cover of ground vegetation species was determined within 128 randomly placed 1m^2 permanent vegetation plots nested within the study sites. No significant correlation was found between biological diversity (Shannon index) and percent introduced species. The presence of introduced species, however, was significantly greater within the periphery plots with the greatest presence found along the disturbed edges, up to 85% cover on average. Dominant introduced species included *Daphne laureola, Agrostis capillaries,* and *Holcus lanatus.* Introduced species were also detected in the interior forest sites (average 3.4% cover), which suggest the need for a more effective invasive species management plan. The broader implications of introduced species invasion with respect to ecosystem management issues and restoration initiatives are discussed.

Limitations

- The vegetation inventory was conducted during July and August 2002; therefore, species that occur outside of this growing window were not accounted for.
- Vegetation inventory is only of the 1m^2 vegetation plots in selected quadrats; therefore, the inventory is not an inclusive species list for the entire study site.
- Grass identification was mostly done *in situ* with reference to two guidebooks followed by herbarium verification of collected samples.

Introduction

Long-term monitoring is necessary to document ecological change and response, as it is a continual process perpetuated by changing environmental conditions, from both natural- and anthropogenic-induced causes on local and global scales. In light of this understanding, the purpose of the study is to monitor the extent of introduced plant species invasion at Royal Roads University with respect to a reference site, and to begin a preliminary analysis of abiotic interactions on the spatial and temporal distribution of these species. This is first phase of a long-term invasive species monitoring study that will enable documentation of environmental change and allow for adaptive ecosystem management.

The Royal Roads University (RRU) property is situated within the endangered Coastal Douglas fir (CDF) biogeoclimatic zone of southeastern Vancouver Island, an area bounded by the Georgia Basin. The CDF zone is a distinct forest type that only occurs within a small area of British Columbia, limited to a strip of southeastern Vancouver Island, a few islands in the Gulf of Georgia and a small, narrow area of the mainland. These areas represent a unique suite of British Columbia's biodiversity in which about 50 plant species are exclusive to this zone (Nuszdorfer *et al*. 1991). Garry oak ecosystem is just one of the unique and diverse associated ecosystems within this zone that posses a significant number of habitat and species at risk (GOERT 2002). In fact, little of the CDF forests still exist in an unmodified form, and the sustainability of the zone is under continual stress from urban/rural development, introduced species invasion and climate change (GOERT 2002; McPhee *et al*. 2000; Haber 1996; Vitousek, *et al*. 1996). At present, introduced grasses and shrubs such as Scotch broom dominate most of the open woodland sites and provide little opportunity for native species to prosper or even exist (Haber 1996).

The RRU property covers a total of 229 hectares of which 180 hectares is forested land that comprises a unique collection of ecotypes, including veteran growth, mixed forest and wetlands. Since the early 1900s, the RRU property has undergone much land alteration and has had an assortment of non-native plant species introduced to the area. Some of these introduced species have become well established in modified areas of the campus core, and in some places these species have become invasive to the native plant community (Ryan *et al*. 1995).

Presently, the RRU property contains many introduced grass and shrub species that have invasive potential and are listed as posing the highest threat to the CDF zone (Ryan *et al*.1995; GOERT 2002). The introduced species are primarily of Europe or Asia origins that have been brought over by people for combination of aesthetic reasons, utilitarian use, or by accident. Although humans are the initial vectors of introduction, the subsequent local spread of successful introduced species is also facilitated by wildlife, wind and water (Mack *et al.* 2001). Introduced species are considered invasive if they are able to spread rapidly and aggressively compete with and displace native species to form dense populations. These invasions interfere with the natural structure and function of the native community (Haber 1996). Typically, invasive species are generalists that can thrive in a range of environmental conditions and some are well adapted to disturbed sites. They are able to facilitate ecosystem change by displacing native species and out-competing other organisms for light, space, and water. This can occur through habitat alteration, such as shifting soil nutrient levels (Prasad & Kushwaha 2001; Schmitz & Simberloff 1997).

Study Objectives and Approach

1. To continue long-term study of the three existing SI/MAB 1-hectare biodiversity plots established at RRU in 1999 (2 plots) and 1 plot established at Rocky Point in 1994.
2. To establish and monitor four 20m^2 plots according to SI/MAB protocols in the interior forest of RRU.
3. To inventory the vascular groundcover species and quantify the relative abundance of introduced plant species to determine the extent of introduced species in selected areas of RRU.
4. To investigate the potential effects of introduced species on the abundance and species diversity of native species.

Location and Description of the Plots

The study was conducted within the two 1-hectare SI/MAB plots located in periphery of RRU campus, and within four newly established 20 m^2 quadrats located in the interior forest of the campus. The two 1-hectare periphery sites each span across three distinct ecotones. The Old Field plot spans across an old up-land field to a mature Douglas fir forest. A gravel road bisects the plot and was treated as an ecotone on to its self. The Salt Marsh plot spans across a salt marsh area, to a shrubby transition area, and a mature Douglas fir forest. The Rocky Point 1-hectare SI/MAB plot, located west of Victoria in the Municipality of Metchosin, was used as an off-site reference.

The RRU plots were established in different areas of the campus to capture the diversity of ecosystem structures and land-use influences. The periphery plots are situated in disturbed areas of the campus that are fragmented by natural (tidal activity) and human disturbance (trails and gravel road). In comparison, the interior plots are situated in a relatively homogenous stand that is buffered from human use areas and forest edge effects

Both RRU and Rocky Point are located within the Coastal Douglas fir moist maritime sub-zone. In general, Douglas fir is the dominant tree with western red cedar and grand fir also present. salal and Oregon-grape are common shrub layer species with bracken fern, trailing blackberry, snowberry and bearded fescue in the herb layer (Nuzdorfer *et al*. 1991).

Methods

Vegetation Inventory Protocol

The 1-ha periphery plots were divided into their distinct ecotones for a finer vegetation characterization and analysis of the plots. Vegetation plots of 1m^2 were randomly established within the four forest interior quadrats and within the delineated transition zones of plots 1 and 2. Four permanent 1m^2 vegetation were established per randomly selected quadrat of the delineated areas. A random number generator also provided the coordinates for the distance from the mid-line of the quadrat and the distance to alternating sides. A fixed 1m^2 square made from PCV pipe was used to define the vegetation plot area and aluminum stakes were erected in each corner to mark its permanent location.

Analytical Methods

The assessment of species composition and groundcover biological diversity among the vegetation plots was accomplished using measurements of species abundance, species frequency and the Shannon index for species diversity. The species abundance was calculated by summing the relative percent cover of each species by study sites, and the species frequency was calculated by a presence/absence count per vegetation plot of the study sites. The Shannon diversity index was used to assess the species diversity because it includes both a species count and evenness, which is considered useful for describing ecological trends (Lewis *et al.* 1988; Stiling 1999; Magurran 1988). The Shannon index was calculated for each study site to compare the diversity among the different ecological areas. The Shannon index was also calculated per vegetation plot of the study sites to assess the correlation between diversity and percent cover of introduced species.

A variety of statistical tests were applied to look for patterns between the species composition and species diversity. These tests included one-way ANOVAs and Pearson correlations.

Results

Extent of Introduced Species

In general, the grassy area of the Old Field site (zone 1) contained the highest average percent cover of introduced species overall (85%). The transition area of the Salt Marsh (zone 2) had the next highest presence of introduced species (31% on average) and the Interior Forest exhibited a small but detectable presence of invasive species (3.4% on average). Invasive species were absent in the Rocky Point reference plot (Table 1).

Table 1: Introduced plant species percent cover statistical summary among study sites.

	Royal Roads Campus							
	Old Field			Salt Marsh			Interior Forest	Rocky Point
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3		
Introduced species richness	16	18	8	6.0	7.0	2.0	2.0	0
Average cover	84.7%	46%	11%	22%	30.5%	26%	3.4%	0
Median cover	92%	50.5%	65%	10%	23%	16%	10%	0
Range	54 - 100%	3 - 80%	0 - 34%	0 - 64%	0 - 100%	0 - 93%	0 - 23%	0
Std. Dev	13.7	24.5	10.9	24.8	29.0	27.1	5.9	0

A one-way ANOVA of the study sites revealed a significant difference among the mean percent cover of introduced species in the study sites ($p=0.0001$). The 95% confidence intervals used in multiple comparison tests indicated the percent cover of introduced species was significantly different among the Old Field zones ($p \geq 0.05$). On average, zone 1 of the Old Field had 46% more introduced species than zone 2 of the Old Field. There was no significant difference among the Salt Marsh zones in terms of the percent cover of introduced species; however, the Salt Marsh zones have significantly more introduced species than the Interior Forest and significantly less than zones 1 and 2 of the Old Field (Figure 1).

For the RRU forested sites (zones 3 of the Old Field and Salt Marsh, and the Interior Forest), there was a significant difference among the mean percent cover of introduced species in the sites ($p \geq 0.05$). Salt Marsh zone 3 is most different from the Interior Forest at 87% more introduced species on average (Figure 1).

The boxes indicate the 75^{th} and 25^{th} percentile. The whiskers are the 90^{th} and 10^{th} percentiles and the line within the box indicates the median. Asterisks indicate outliers. Sites followed by the same letter are not significantly different from each other ($p \geq 0.05$).

Old Field Introduced Species

The Old Field, zone 1 was dominated by four introduced grasses dominating the vegetation cover: Velvet grass (*Holcus lanatus),* 21% abundance; Colonial Bentgrass (*Agrostis capillaries),* 20% abundance; Kentucky Bluegrass (*Poa pratensis)*, 15% abundance and Quackgrass *(Agropyron repens),* 11% abundance (Figure 2). [Note: Abundance was calculated by summing the relative percent cover by species per study site.]

The dominant introduced species within the Old Field zone 2 (transition zone) were Quackgrass at 11% abundance, and Velvet grass at 10% abundance. Orchard Grass (*Dactylis glomerata*) occurred exclusively in this zone at 8% abundance and a frequency of 9 of 16 vegetation plots.

Zone 3 (forested area) had the lowest percent cover of introduced species (11%) of the Old Field sites; 3 of 16 vegetation plots did not have any introduced species. The dominant introduced species of this zone were Wall Lettuce (*Lactuca muralis*) at 3% abundance and Daphne *(Daphne laureola)* at 1% abundance.

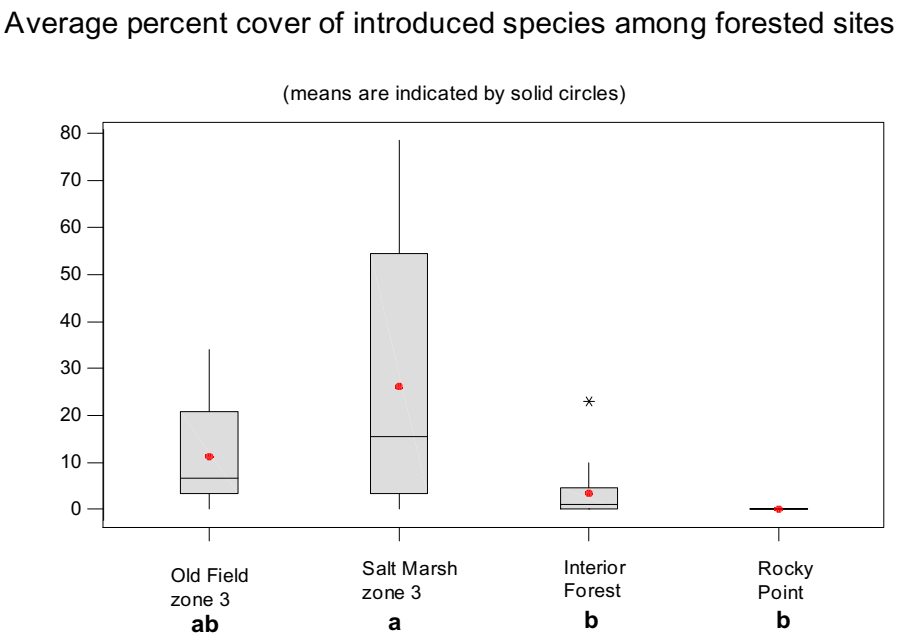

Figure 1: Average percent cover of introduced species among forested sites.

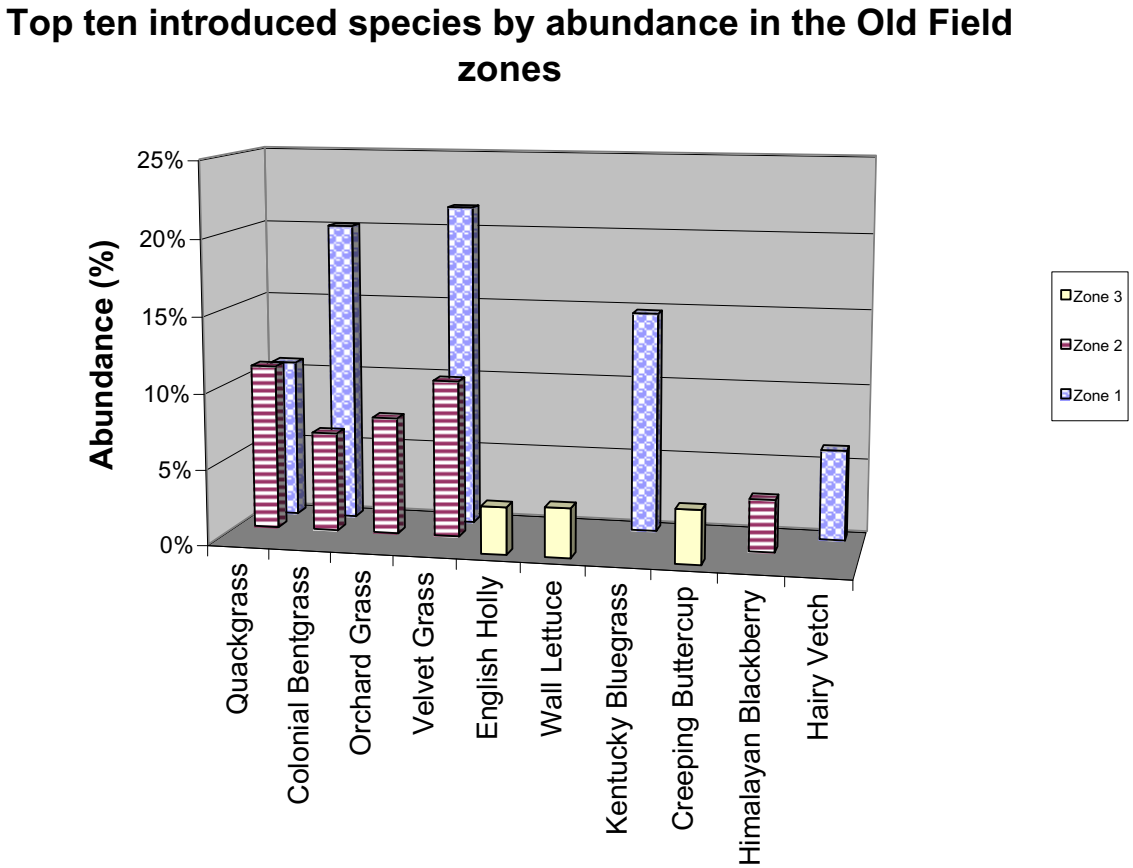

Figure 2: Top Ten introduced species by abundance in the Old Field zones.

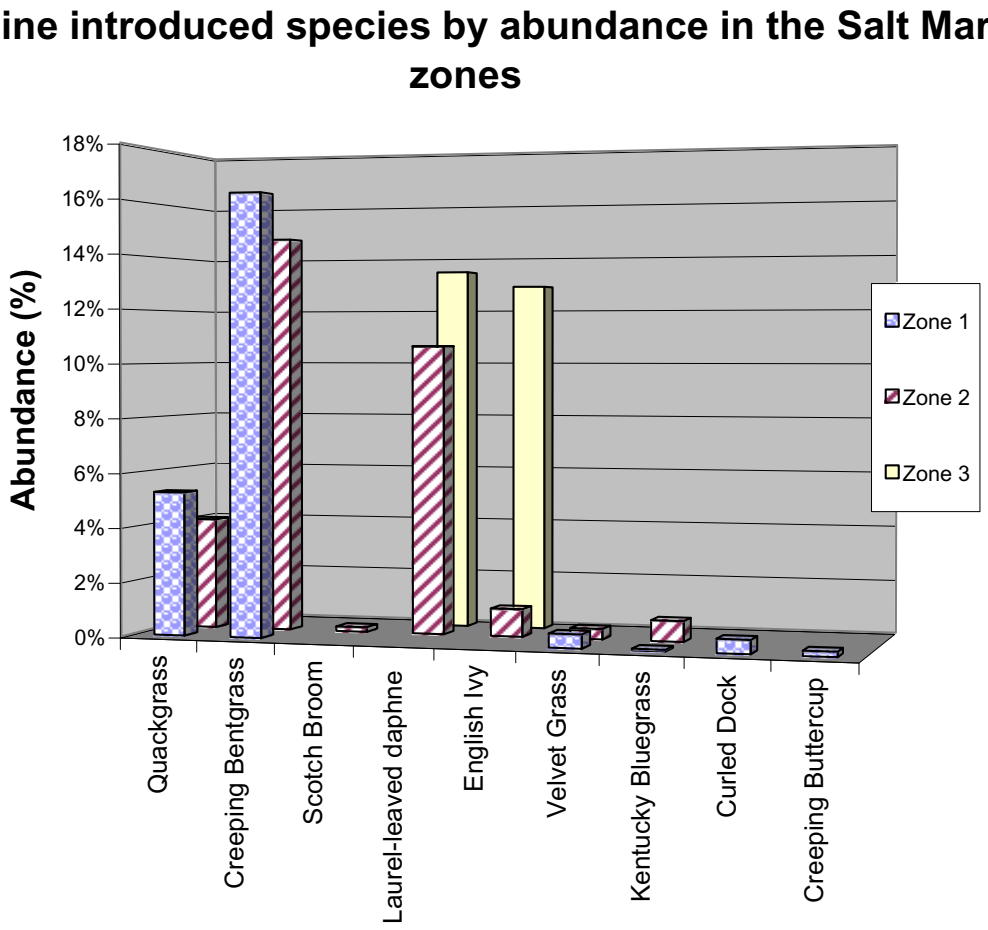

Figure 3: Top nine introduced species by abundance in the Salt Marsh zones.

Salt Marsh Introduced Species

The dominant introduced species found in the Salt Marsh zone 1 were Creeping Bentgrass (*Agrostis stolonifera*), with an abundance of 16%, and Quackgrass with an abundance of 5% (Figure 3)

Zone 2, the transition area between the marsh and the forest, had the highest occurrence of introduced species with an introduced species richness of 7 and 31% average percent cover of introduced species. Creeping Bentgrass and Daphne accounted for majority of the introduced species in this zone (abundance of 15 % and 11%, respectively).

Zone 3 (forested area) had the lowest introduced species richness of the zones with 2 species, Daphne and English Ivy. These species, however, occurred in enough abundance and frequency to account for an overall average percent cover of 26%.

Interior Forest Introduced Species

No introduced species were found in 8 of the 16 of the Interior Forest site vegetation plots. Of the plots with introduced species, Wall Lettuce was dominant at 2.5% abundance, and English Holly was the co-dominant at 1.1% abundance. Daphne was also observed in the forest, however, no stems occurred within the vegetation plots and therefore they were not included in the inventory.

Species Diversity Comparison Among Study Sites

In general, the Old Field offers the highest species diversity of the study sites. Specifically, Old Field zone 2 (transition area) has the highest diversity, evenness and species richness among the study sites. This may be attributed to wide variety of micro-habitats offered here including light intensity and soil disturbance.

The Salt Marsh ranks second in species diversity among the study sites. Within the Salt Marsh, zones 1 and 2 had the highest species diversity (2.27 and 2.17, respectively) and evenness (0.71 and 0.69, respectively). In contrast, zone 3, the forested area, offered the lowest species richness (15 species)

Of the forested sites, zone 3 of the Old Field had the highest species richness (29 species) and species diversity (1.57). Rocky Point had the highest evenness (0.51). However, it has the lowest groundcover species richness at only 5 species. In contrast, the Forest Interior had the lowest evenness (0.36) and a low diversity (0.98).

Table 2: Groundcover species diversity comparison among study sites.

Study site	Zone	Species Richness (S)	Shannon index (H')	Evenness (E)	Total vascular species
Old Field	1	27	2.22	0.67	
	2	34	2.76	0.78	
	3	29	1.57	0.47	65
Salt Marsh	1	24	2.27	0.71	
	2	22	2.17	0.69	
	3	15	1.29	0.48	45
Interior Forest	n/a	15	0.98	0.36	15
Rocky Point	n/a	5	0.82	0.51	5

The species diversity of the respective study sites was highly influenced by the presence of introduced species in the inventory. The species diversity of all groundcover species as compared to species diversity of only native species is shown below, with the percent difference between all species diversity and native species diversity indicated (Figure 4).

The bar chart indicates the relative proportion of introduced species and native species influencing species diversity. The blue bar represents all species and the red bar represents native species; the difference between the two bars suggests the influence of introduced species on species diversity.

The proportion of introduced species demonstrated the large variety of introduced species found in widespread distribution within each of the sites. The species diversity of the Old Field zones 1 and 2 were most influenced by the presence of introduced species. This influence was less pronounced in the Salt Marsh, and was minimal in the relatively undisturbed Interior Forest.

Discussion

Introduced plant species are found in varying abundance and frequency in each of the RRU study sites, whereas no introduced species are found in the Rocky Point reference site. The species composition and percent cover of introduced species varies considerably among study sites, which demonstrates the complex range of environmental factors and limits of tolerance contributing to the structure and function of each of the different ecosystems.

The extent of introduced species at Royal Roads University is greatest within the periphery study sites (Old Field and Salt Marsh), which are areas with anthropogenic disturbance and limited forest buffer. The Old Field displays the highest percent cover of introduced species within its grassy area (zone 1), which was once tilled and used for animal grazing. The introduced grass species that dominate this area (velvet grass, colonial bentgrass and Kentucky bluegrass) were likely introduced to the area through animal feed and have since successfully reproduced and distributed throughout the open area. Since this time, the dense cover of grass species and disturbed soil has likely become a positive feedback situation of impeded shrub and tree succession and increased vulnerability to grass invasion by the lack of forest cover. Previous studies have indicated that forest cover may be necessary to generate the patchy, competitive environment to foster native species diversity at the expense of introduced species (Carey *et al*. 1999; Tysell & Carey 2000).

The great varieties of introduced species (16 species) that currently occupy the Old Field have overwhelmed the native species diversity. A gradient of decreased introduced species percent cover is evident from the grassy area to the forested area (zone 3), which suggests the forest is providing a buffering effect against species invasion. Light availability is also a likely contributor to this buffer.

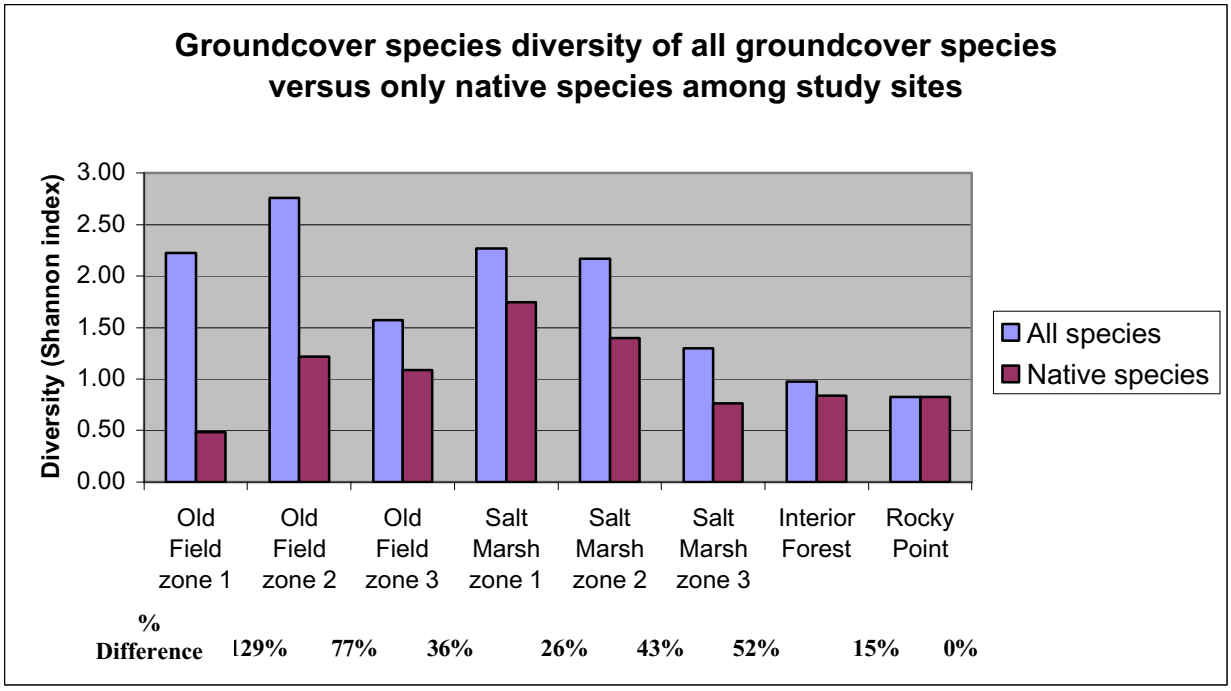

Figure 4. Species diversity of all groundcover species compared to native species among study sites.

The Salt Marsh also exhibits a substantial percent cover of introduced species, however, unlike the Old Field, a gradient of introduced species does not appear across the Salt Marsh zones. In this site, the percent cover of introduced species is relatively similar across the zones (22%-32%), however; the species assemblages are drastically different. The distributions of species within this study area are probably highly limited by the salinity gradient and fluctuating water inundation characteristic of this ecosystem. The Salt Marsh forested area (zone 3) does not appear to buffer species invasion as successfully as the Old Field, and the monotypic tracks of Daphne found within this area may be attributed to the proximity of an ornamental garden in which Daphne was purposely planted. Likely vectors for its distribution are birds eating its berries.

The Salt Marsh species diversity is most greatly influenced by introduced species in zones 2 and 3 (transition and forested area). The large presence of Daphne in these areas has likely biased the overall diversity by inflating the species richness and percent groundcover in an otherwise sparsely vegetated understory.

Of the RRU study sites, the Interior Forest site appears to be most resistant to the establishment of introduced species. The relatively undisturbed forest appears to have provided a moderate buffer against introduced species invasion; however, the sporadic occurrence of Wall Lettuce (2.5% abundance) and English Holly (1.1% abundance) may indicate a pervasive problem. Considering the invasive potential of English Holly (McPhee *et al.* 2000; Haber 1996), its small but detectable presence within the Interior Forest will likely increase unless actively managed. The low species diversity of the Interior Forest as compared to the RRU periphery sites indicates the limited immigration of species from adjacent ecotones.

The Rocky Point reference site has no introduced species and relatively low species diversity. This apparent resistance to introduced species may be attributed to a saturated niche by the dense salal cover. The dominance of salal may be successfully subverting the establishment of other native and introduced species, including English Ivy and Daphne that were found in all of the forested sites at RRU. Alternately, it is possible that these species have not been introduced to the area yet.

The overwhelming dominance of salal at Rocky Point resulted in low species diversity for groundcover species; however, the inclusion of mosses, lichens and fungi would likely produce a higher result. This virtual desert for species diversity is an area for future study.

Conclusion

Introduced species are present at varying abundance and frequency in all the SI/MAB research plots at Royal Roads University, which suggests the need for the implementation of an invasive species management program. Areas of particular concern are zone 1 of the Old Field, which is invaded by introduced grasses, and zones 2 and 3 of the Salt Marsh, in which Daphne is the dominant groundcover species, particularly around the perimeter of the forested area. Introduced species are also present, although with much less abundance, in the relatively undisturbed Interior Forest. This small but notable presence of introduced species in the Interior Forest suggests the forest buffer provides some resistance to invasive species, however, it also indicates a pervasive problem with certain introduced species. An invasive species management plan should be implemented to eradicate these introduced species and to prevent further migration of these species into the surrounding area, as a means to maintain the native vegetation of the endangered Coastal Douglas fir biogeoclimatic zone.

This study also suggests that species diversity, as an indicator of introduced species invasion, may be more useful when viewed over time. Species diversity can be biased or skewed by introduced species richness and vegetation density of the study sites. Further monitoring of introduced species cover and species diversity may also reveal species competition, and species evenness and native species diversity shifts. The rate of environmental change may also prove to be a robust and broadly applicable indicator of a site's resistance or susceptibility to introduced plant species invasion.

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References

Baskin, Y. (1998). Winners and losers in a changing world. Bioscience. 48(10), 788.

BC Environment. (date unknown). Vancouver Island air data archive. Air Resources Branch. Ministry of Water, Land, and Air protection. Retrieved October 2, 2002, from http://www.elp.gov.bc.ca:8000/pls/aqiis/archive.report.

Bright, C. (1999). Invasive species: pathogens of globalization. Foreign Policy, 116, 50

Canada Department of Agriculture. (1978). The Canadian system of soil classification. (2nd ed.) Ministry of Supply and Services Canada. Ottawa, On.

Castle, G. (Editor) (1995) Hatley park: An illustrated anthology. Friends of Hatley Park Society, Colwood, BC.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, L.C. Irland, A.E, Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks, & B.M. Wotton. (2001). Climate change and forest disturbances. BioScience. 51(9), 723-734.

Dallmeier, F & J. Comiskey. (1994). Methodology for the establishment of permanent plots biodiversity measuring and monitoring course. Smithsonian Institution/Man and the Biosphere Species diversity program. Washington, DC.

ESAC annual report (1997). Establishment and monitoring of permanent ecological plot in a Coastal Douglas Fir forest and a Garry Oak woodland at the Rocky Point Department of Defence lands. Pacific Forestry Centre. Natural Resources Canada. Retrieved July 2, 2002, from http://www.pfc.forestry.ca/programs/esac/reports/1997/1997-p002_e.html

Garry Oak Ecosystem Recovery Team. (2002). Towards a decision tool to address invasive species in Garry Oak and associated ecosystems. Retrieved July 3, 2002 from http://www.essa.com/projects/descriptions/garryoak/top10.htm.

Haber, E. (1996). Impact of invasive plants on species and habitats at risk in Canada. National Botanical Services, Ottawa. Retrieved September 27, 2002 from http://infoweb.magi.com/~ehaber/impact.html.

Hansen, A.J. (2001). *IN:* Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. L.C. Irland, Ae.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks and B.M. Wotton. 2001. Climate change and forest disturbances. Bioscience 51(9),723-732.

Hendeveld, H.G. (2001). Projections for Canada's future: A discussion of recent simulations with the Canadian Global Climate Model. Meteorological Service of Canada. Retrieved September 27, 2002 from http://www.msc-smc.ec.gc.ca/saib/climate/docs/ccd_00-01.pdf.

Hendrix, P.F. & P.J. Bohlen. (2002). Exotic earthworm invasions in North America: ecological and policy implications. Bioscience 52(9), 801-811

Hitchcock, K.C.L., A. Cronquist, M. Ownbey & J.W. Thompson. (1969). Vascular Plants of the Pacific Northwest. University of Washington Press, Seatle, WA.

Hubbard, W.A. (1969). The grasses of British Columbia. B.C, Provincial Museum, Victoria, B.C, Handbook No. 9.

Kaiser, J. (2000). Does biodiversity help fend off invaders? Science 288(5467),785

Kalra, Y.P. & D.G. Maynard. (1991). Methods manual for forest soil and plant analysis. Forestry Canada, Northwest Region, North For. Cent., Edmonton, Alberta. Inf. Rep. Nor-X-319.

Kareiva, P.M., J.G. Kingslover & R.B. Huey (editors). (1993). Biotic interactions and global change. Sunderland: Sinauer.

Klinka, K. V.J. Krajina, A. Ceska & A.M. Scagel, (1995). Indicator plants of coastal British Columbia. UBC Press, Vancouver, BC.

Koptsik, G.N. & V. Serguei. (1999). Assessment of soil quality for biodiversity conservation in boreal forest ecosystems. *IN:* D.E. Stott, R.H. Mohtar & G.C. Steinhardt (editors). 2001. Sustaining the global farm. Selected papers from the 10th International soil conservation organization meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Lewis C.E., B.F. Swindel & G.W. Tanner. (1988) Species diversity and diversity profiles: Concept, measurement, and application to timber and range management. Journal of Range Management 41 (6), 466-469.

Lozon, J.D. & H.J. MacIsaac. (1997). Biological invasions: are they dependent on disturbance? Environmental Reviews. 5, 131-144.

Luttmerding H. A., D.A. Demarchi, E.C. Lea, D.V. Meidinger & T. Vold, (editors). (1990). Describing ecosystems in the field. (2nd ed.) Second Printing, Ministry of Environment, Lands and Parks, and Ministry of Forests, Victoria, BC.

Mack, R., N. Lonsdale & W. Mark. (2001). Humans as global plant dispersers: getting more than we bargained for. Bioscience 51(2), 8 & 95.

Magurran, A.E. (1988). Ecological diversity and its measurement. Princeton University Press, Princeton, N.J. 179 pp.

Manahan, S.E. (2000). Environmental chemistry. (7th ed). Lewis Publishers. Boca Raton. 300 p.

McKay, D.J. & J.D. McTaggart-Cowan. (1977). An inter-comparison of radiation shields for auto stations. *IN:* U.S. Environmental Protection Agency. 1989. Quality assurance handbook for air pollution measurement systems Volume 4. Research Triangle Park, North Carolina.

McPhee, M., P.Ward, J. Kirby, L. Wolfe, N. Page, K. Dunster, N.K. Dawe & I. Nykwist. (2000). Sensitive Ecosystems Inventory: East Vancouver Island and Gulf Island, 1993 – 1997. Volume 2: Conservation Manual. Technical Report Series No. 345, Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Meidinger, D., T. Lee, G.W. Douglas, G. Britton, W. MacKenzie & H. Qian. (2002). British Columbia plant species codes and selected attributes. Version 4 Database. Research Branch. B.C. Ministry of Forests. Retrieved July 8, 2002 from http://www.for.gov.bc.ca/research/becweb/standards-species.htm

Millennia Research. (1997). Archaeological baseline study, Royal Roads: Final Report. Public Works and Government Services. Victoria, BC.

Morrison, S.L. & Molofsky, J. (1999). Environmental and genetic effects on the early survival and growth of the invasive grass *Phalaris arundinacea*. Canadian Journal of Botany 77, 1447-1453.

Naeth, M.A., A.W, Bailey, D.S. Chanasky, & D.J. Pluth. (1991). Water holding capacity of litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. Journal of Range Management. 44(1), 13-17.

Nuszdorfer, F.C., K. Klinka & D.A. Demarchi. (1991). Coastal Douglas fir zone. *IN* Meider, D. and Pojar, J. (editors). Ecosystems of British Columbia. BC. Ministry of Forests, Victoria.

Olson, G. W. (1981). Soils and the Environment: A guide to soil surveys and their applications. Chapman and Hall Ltd., London.

Pojar, J. & A. MacKinnon. (editors). (1994). Plants of Coastal British Columbia. Lone Pine Publishing. Edmonton, AB.

Peterson, D.J. & R. Prasad. (1998). The biology of Canadian weeds 109. *Cytisus scoparius* L. Canadian Journal of Plant Science. 78, 497-504.

Prasad, R. & S. Kushwaha. (2001). Ecology of invasive weeds: impact and management of the exotic weeds, gorse (*Ulex europaeus)* and Scotch broom *(Cytisus scoparius)* in British Columbia, Canada. The Proceedings of Asian-Pacific Weed Science Society Conference. Beijing, China.

Prasad, R. (2000). Some aspects of the impact and management of the exotic weed, Scotch Broom *(Cytisus scoparius)* in British Columbia, Canada. Journal of Sustainable Forestry, 10(3), 341-347.

Prasad, R. (date unknown). Scotch Broom, *Cytisus scoparius* L. in British Columbia. Canadian Forest Service, Pacific Forestry Centre. Retrieved November 4, 2002 from http://www.pfc.cfs.nrcan.gc.ca/biodiversity/broom_e.html.

Rapport, D. J. & W. G Whitford. (1999). How ecosystems respond to stress. Bioscience, March 49 (3),193-204.

Roberts-Pichette, P. & L. Gillespie. (1999). Terrestrial vegetation Biodiversity Monitoring protocols. EMAN Occasional Paper Series. Report No.9 Ecological Monitoring Coodinating office.

Roberts-Pichette, P. (1995). Framework for monitoring biological change (species and species groups) within the Ecological Monitoring and Assessment Network in Canada. Environment Canada. Retrieved June 12, 2002 from http://www.eman-rese.ca/eman/reports/publications/framework/intro.html.

Robinson, M. (1995). Royal Roads: A celebration. Natural Light Productions. Victoria, BC.

Ryan, M., G. Radcliffe, & G. Butt. (1995). Ecological assessment of Royal Roads property. Madrone Consultant Ltd.

Schmitz, D.C. & D. Simberloff. (1997). Biological invasions: a growing concern. Science and Technology 13(4), 8,33.

Stewart, H. & R. Hebda. (2000). Grasses of the Columbia Basin of British Columbia. Ministry of Forests Research Program and Royal British Columbia Museum. Victoria, BC.

Tappeiner, J.C., J.C. Zasada, D.W. Huffman, & L.M. Ganio. (2001). Salmonberry and salal annual aerial stem production: the maintenance of shrub cover in forest stands. Canadian Journal of Forest Research 31, 1629-1638.

Thysell, D.R. & A.B. Carey. (2001). Manipulation of density of *Pseudotsuga menziesii* canopies: preliminary effects on understory vegetation. Canadian Journal of Forest Research 31, 1513-1525.

U.S. Environmental Protection Agency. SW-846 online. Test methods for evaluating solid wastes physical/chemical methods. Retrieved August 20, 2002 from http://www.epa.gov/epaoswer/hazwaste/test/main.htm.

Vitousek, P.M., C.M. D'Antonio, L.L. Loope & R. Westbrooks. (1996). Biological invasions as global environmental change. American Scientist (84), 468-478.

Williamson, M. (1999). Invasions. *IN:* Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. L.C. Irland, A.E. Lugo, C.J. Peterson, D. Simberloff, F.J. Swanson, B.J. Stocks & B.M. Wotton 2001 Climate change and forest disturbances. Bioscience 51(9), 723-732.